Technion
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PASER: Activity Update and Proposed Plans for the Future

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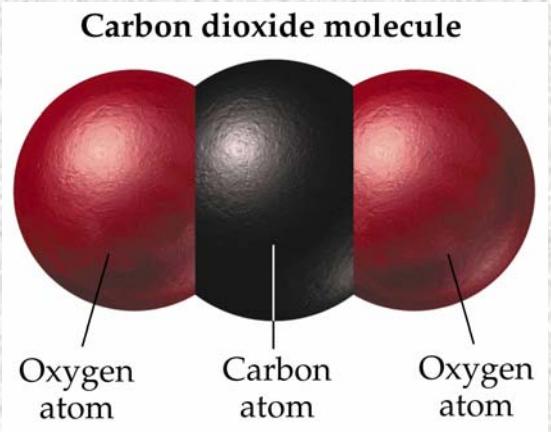
Outline

- *Essence of the PASER*
- *Theoretical Model*
- *Experiment*
- *Essence of the Proposed Program*

Essence of the PASER

Macroscopic Structures

- Cavity (Circular Acc.)
- Coupled cavities (Linear Acc.)
- Electron bunch (Wake-Field Acc.)
- Laser pulse (Laser-Plasma Schemes)

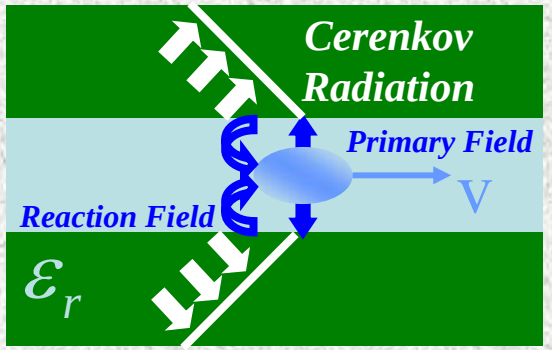


Microscopic Structures

- Atom/molecule (Ar^+,CO_2)
- Dopant in solid-state (Nd:YAG)

Essence of the PASER (macro)

1 Passive Dielectric

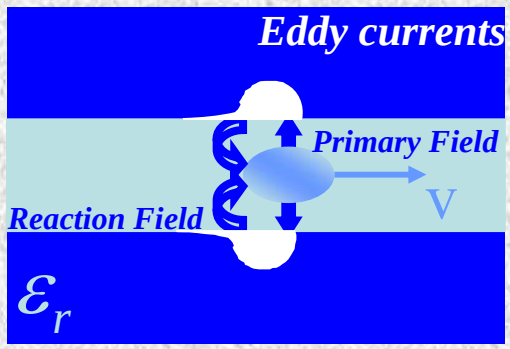


$$\mathrm{Re}(\varepsilon) < (c/V)^2$$

$$\mathrm{Im}(\varepsilon) = 0$$

Decelerating Force

2 Resistive Material

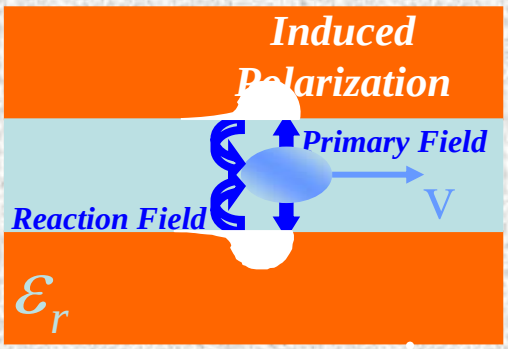


$$\mathrm{Re}(\varepsilon) = 1$$

$$\mathrm{Im}(\varepsilon) = -\sigma / \varepsilon_0 \omega < 0$$

Decelerating Force

3 Active Medium



$$\varepsilon = \varepsilon_{Re} + j\varepsilon_{Im}$$

$$\mathrm{Re}(\varepsilon) > \mathrm{Im}(\varepsilon)$$

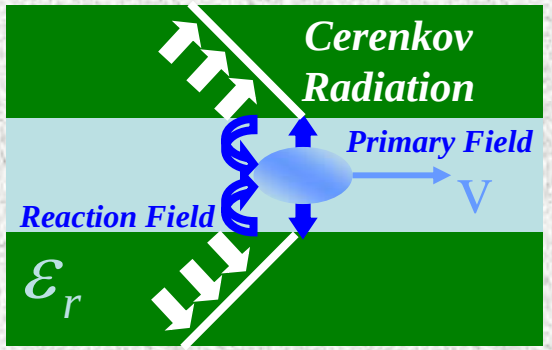
$$\mathrm{Im}(\varepsilon) > 0$$

Accelerating Force

L. Schächter, Phys. Rev. E 53, p. 6427, 1996

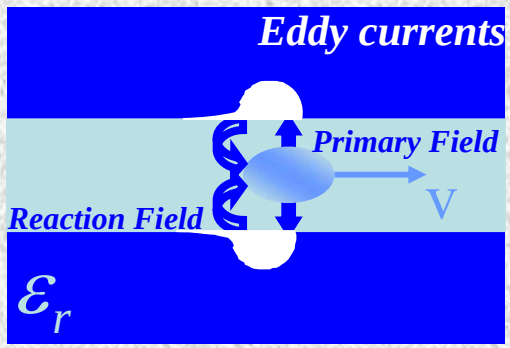
Essence of the PASER (macro)

1 Passive Dielectric



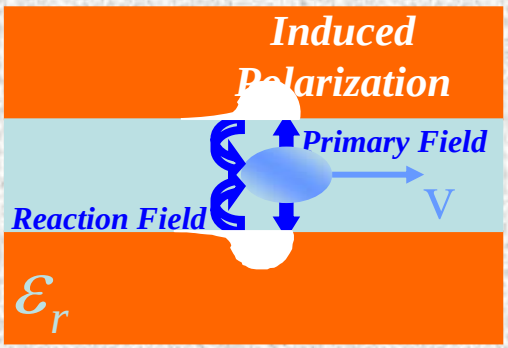
Broadband Field
Broadband Material

2 Resistive Material



Broadband Field
Broadband Material

3 Active Medium

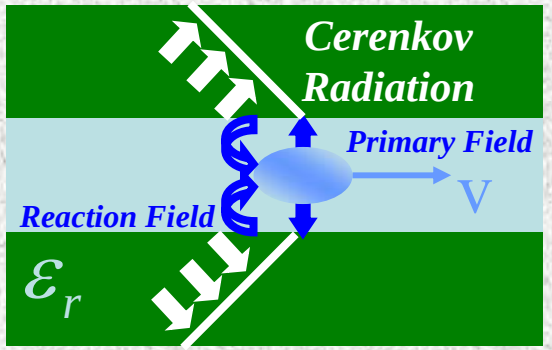


Broadband Field
Narrowband Material

Poor Efficiency!

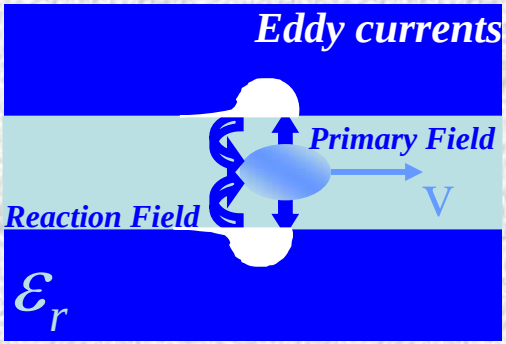
Essence of the PASER (macro)

1 Passive Dielectric



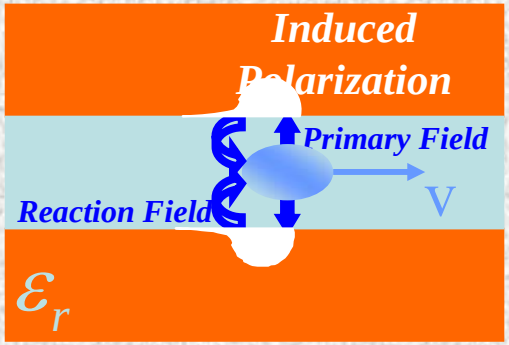
Broadband Field
Broadband Material

2 Resistive Material



Broadband Field
Broadband Material

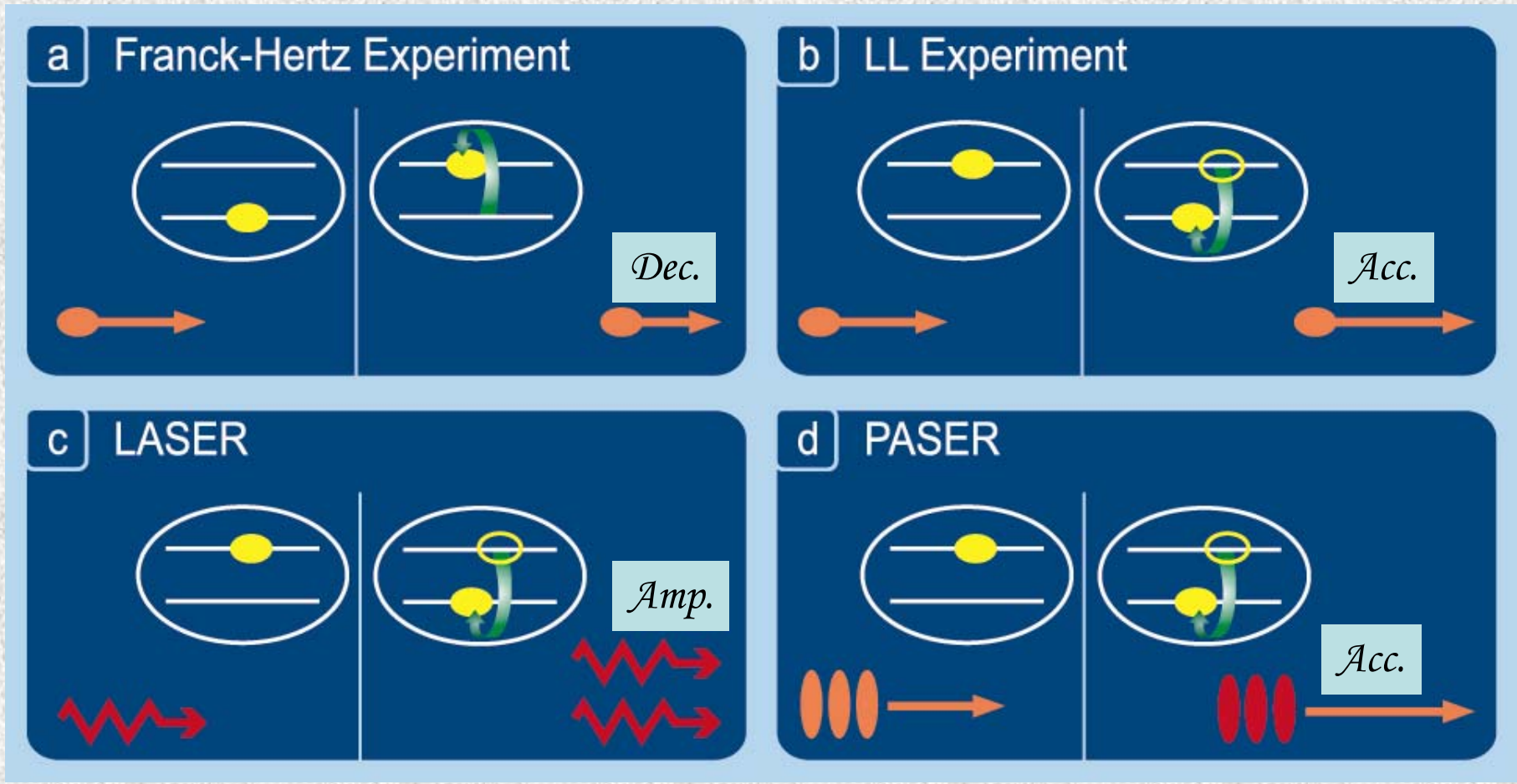
3 Active Medium



Narrowband Field
Narrowband Material

Train of Bunches

Essence of the PASER (micro)

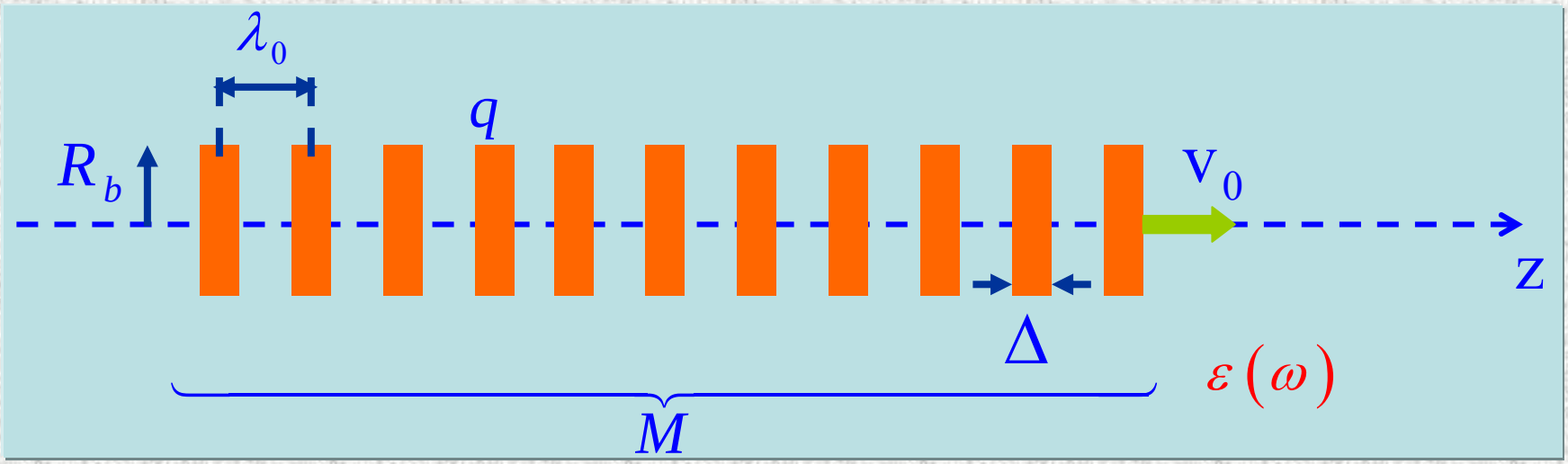


L. Schächter; Phys. Lett. A ., **205**, p. 355-358(1995).

Outline

- *Essence of the PASER*
- *Theoretical Model*
- *Experiment*
- *Essence of the Proposed Program*

Theoretical Model



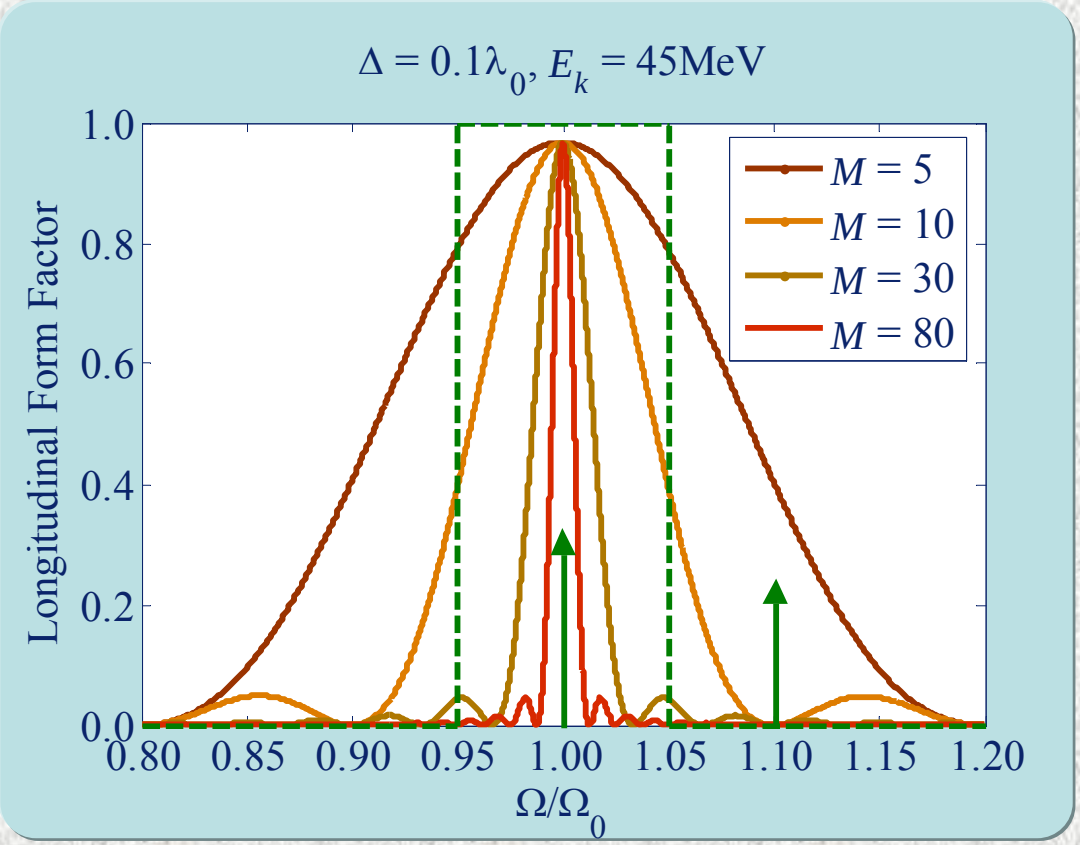
$$\frac{\Delta E_k}{E_k} \simeq \frac{4N_{el}}{\gamma - 1}\left[d\left(\pi r_e^2\right)\frac{w_{act}}{\hbar\omega_0}\right]\mathrm{sinc}^2\left(\pi\frac{\Delta}{\lambda_0}\right)\mathrm{sinc}^2\left(\frac{\pi M}{2\gamma^2}\right)F_\perp\left(2\pi\frac{R_b}{\lambda_0}\right)$$

- # Linear medium
- # Constant velocity
- # Uniform micro-bunches
- # No transverse motion

Banna et al., PRL **97**, 134801, 2006
Banna et al., PRE **74**, 046501, 2006

Theoretical Model

Frequency Selection



$$F_{\parallel} \equiv \mathrm{sinc}^2\left(\pi\frac{\Delta}{\lambda_0}\Omega\right)\frac{\mathrm{sinc}^2\left(\frac{1}{2\beta}M\Omega\right)}{\mathrm{sinc}^2\left(\frac{1}{2\beta}\Omega\right)}$$

$$\mathrm{CO}_2: \begin{cases}\lambda_0 = 10.6\mu\mathrm{m}\\ \lambda_1 = 9.6\mu\mathrm{m}\end{cases}$$

$$\frac{1}{T_2} = 5\times10^8\ \mathrm{sec}^{-1}$$

$M > 30$

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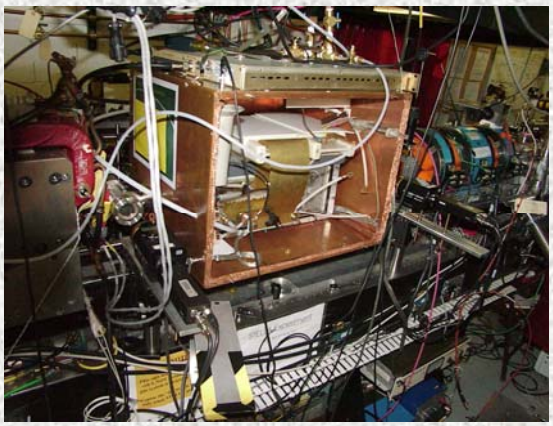
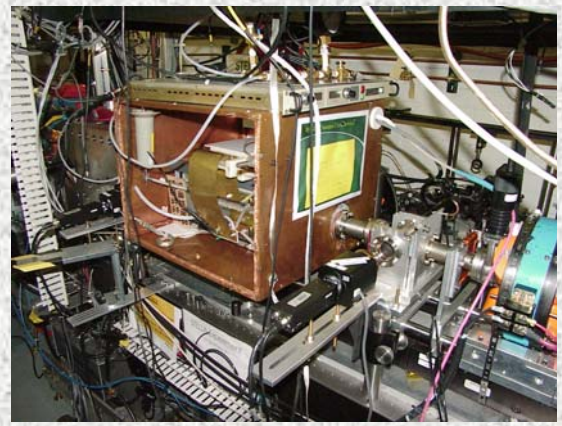
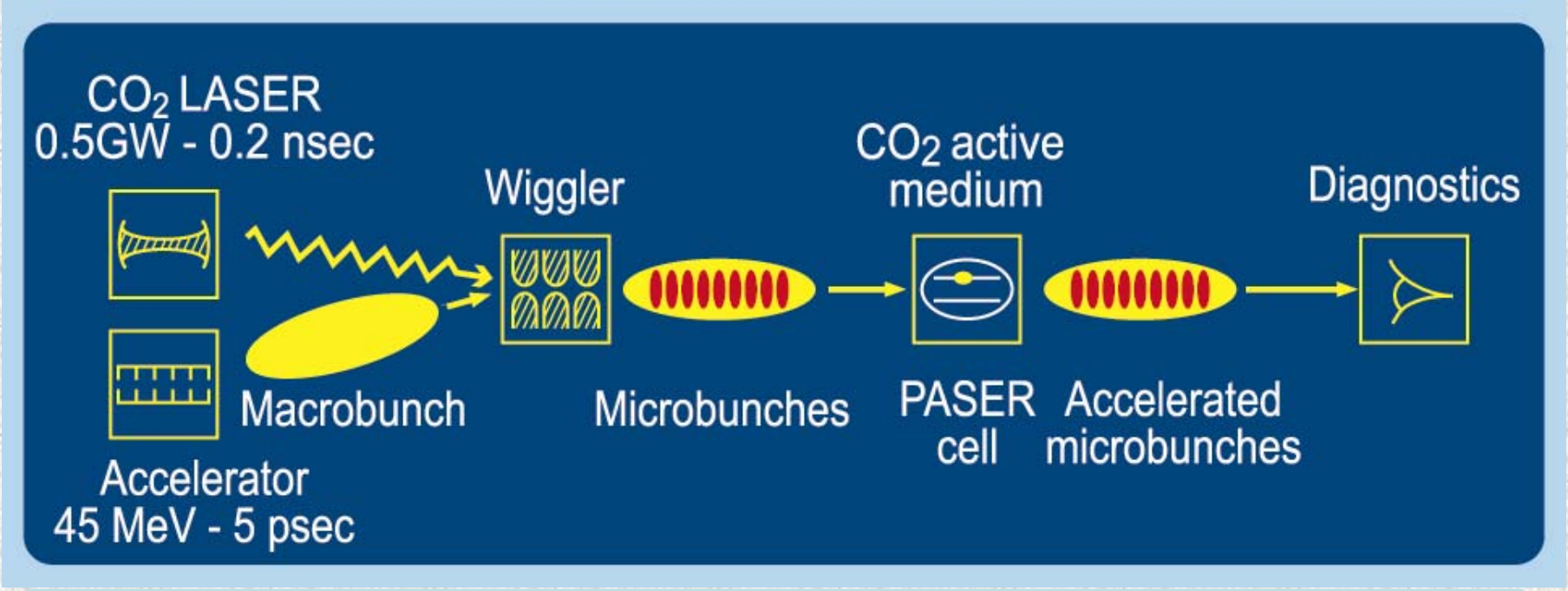
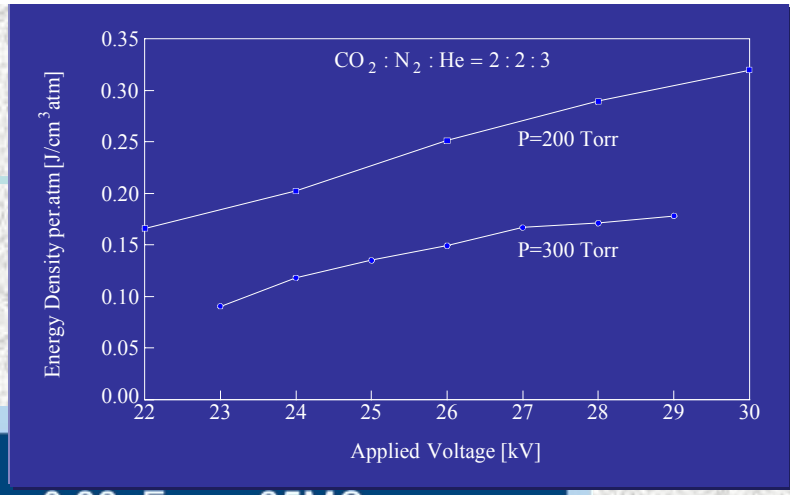


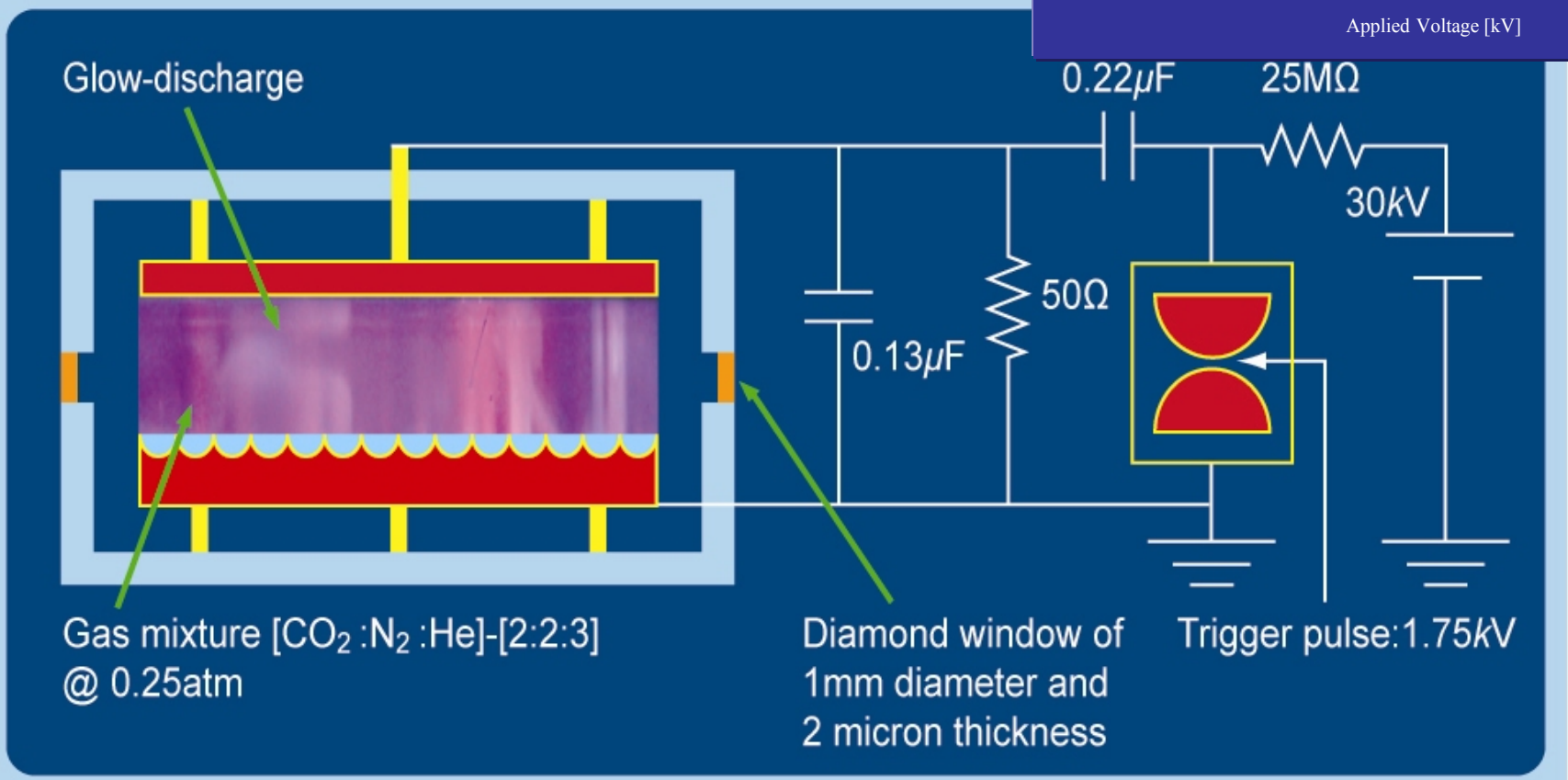
Experiment




CO_2 LASER
0.5GW - 0.2 nsec
Wiggler
CO_2 active medium
Diagnostics
Macrobunch
Microbunches
PASER cell
Accelerated microbunches
Accelerator
45 MeV - 5 psec

Experiment

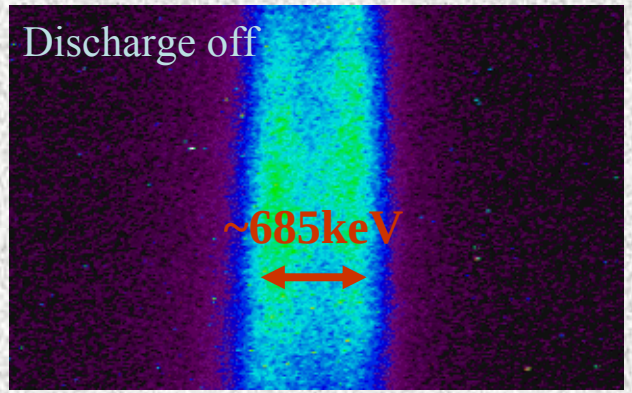

$CO_2 : N_2 : He = 2 : 2 : 3$
P=200 Torr
P=300 Torr
Energy Density per.atm [J/cm^3 atm]
Applied Voltage [kV]
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
22
23
24
25
26
27
28
29
30


Glow-discharge
0.22μF
25MΩ
30kV
50Ω
0.13μF
Gas mixture [CO_2 :N_2 :He]-[2:2:3]
@ 0.25atm
Diamond window of
1mm diameter and
2 micron thickness
Trigger pulse:1.75kV

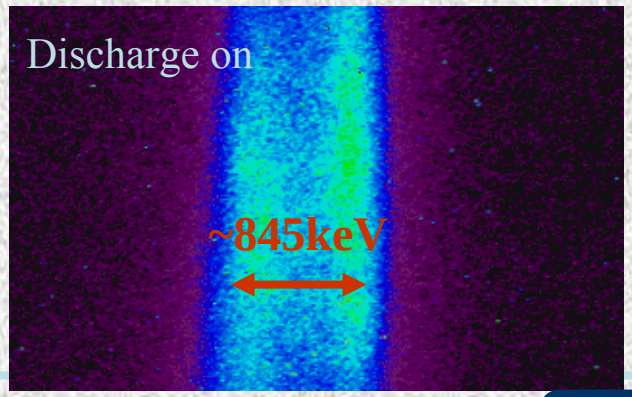
Experiment

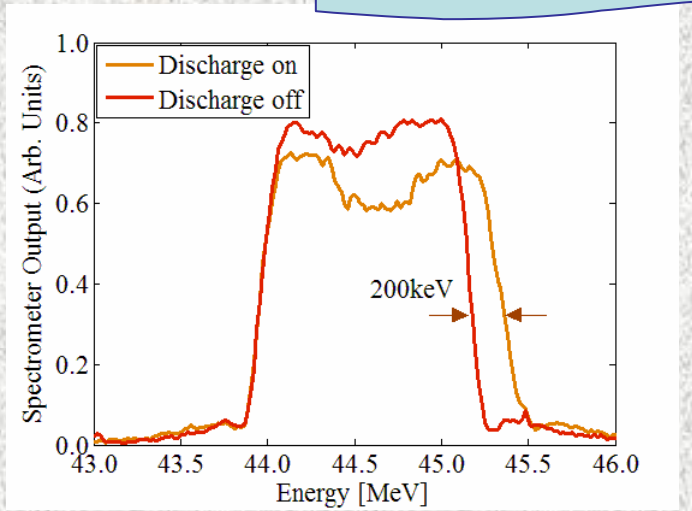
2,000,000 collisions !!

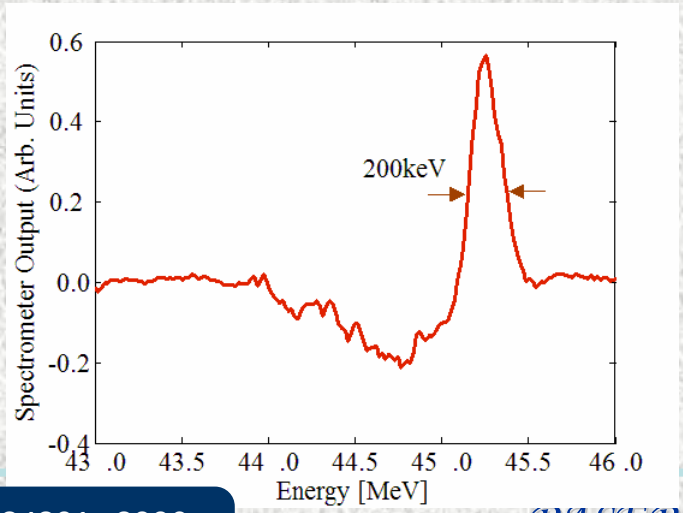
1.5% peak-to-peak energy modulation



Direction of increasing energy







Banna et al., PRL **97**, 134801, 2006
Banna et al., PRE **74**, 046501, 2006

Outline

- *Essence of the PASER*
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Goals of the Proposed Program

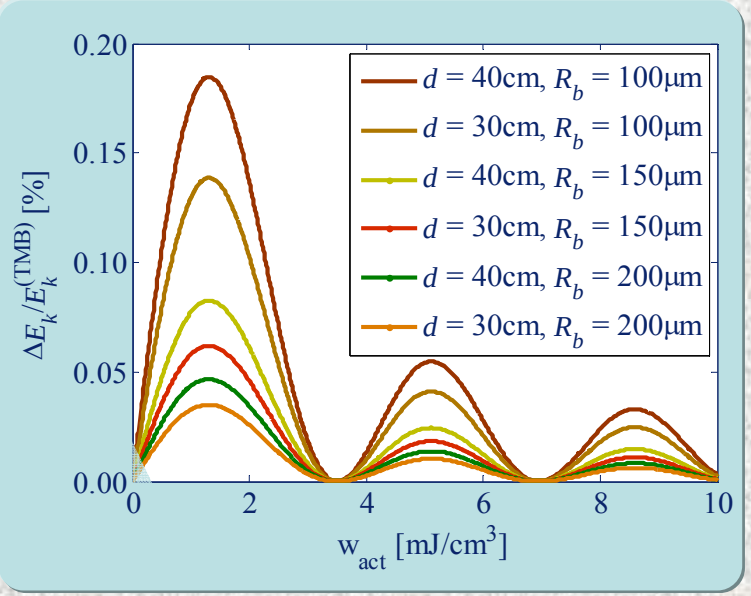
- *Goal #1: High Gradient Operation @ IR* [(i)]
- *Goal #2: Staging of PASER Cells*
- *Goal #3: Future Configurations*

[(i)] *Details in Wayne's talk*

Goal #1: High Gradient

Optimizing the Energy Density

- Collective effects of the entire ensemble of electrons cause oscillating dependence of the energy gain.
- Energy density can be tuned to optimum enabling maximum energy gain.
- The optimum value of the energy density is not affected by the beam size.
- The energy gain is significantly affected by the beam size.



- Apply beam focusing in the cell
- Improve excitation efficiency (discharge)
- Increase the pressure (to 1 atm)

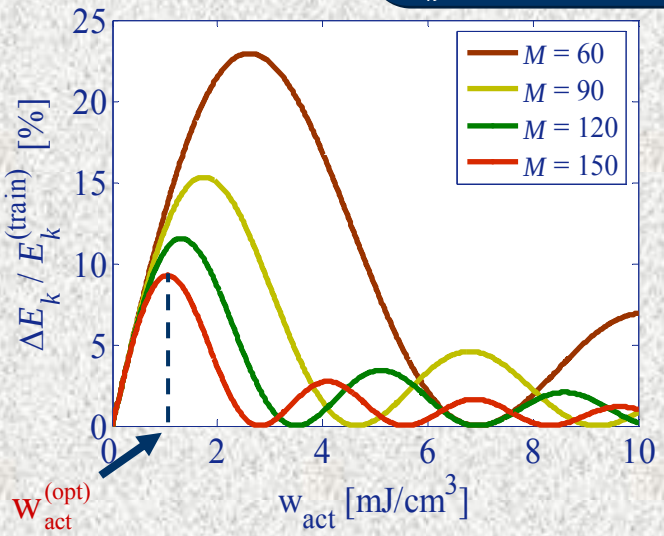
- Goal #1: High Gradient Operation @ IR
- Goal #2: Staging of PASER Cells
- Goal #3: Future Configurations

Goal #1: High Gradient

$T_2 = 5\times10^{-9}$ sec
$N_{el} = 1\times10^{10}$
$\Delta = 1$ μm
$E_k = 45$ MeV

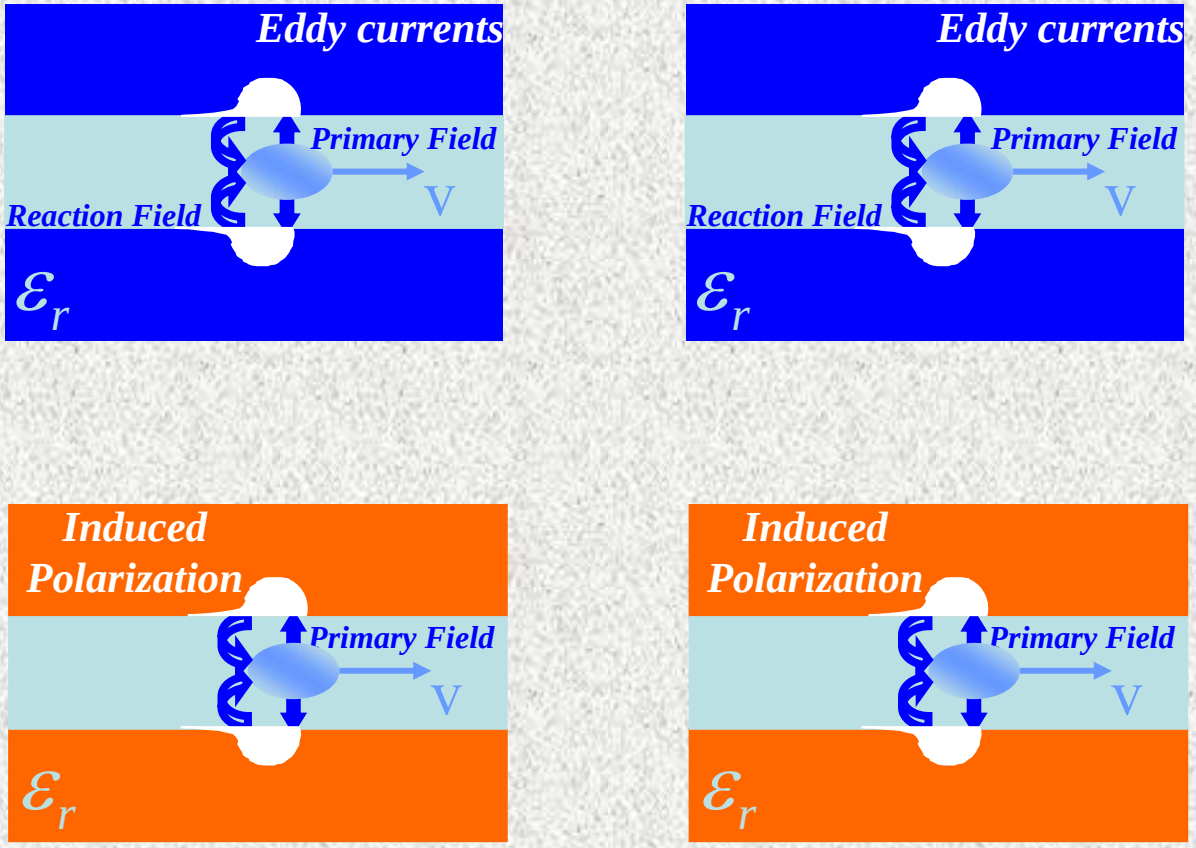
Optimizing the Micro-bunches

- The number of microbunches affects the bandwidth of the energy exchange process.
- The number of microbunches determines the electrons density within each micro-bunch.
- The optimum energy density increases with the decrease of M
- Number of electrons in macro-bunch is constant



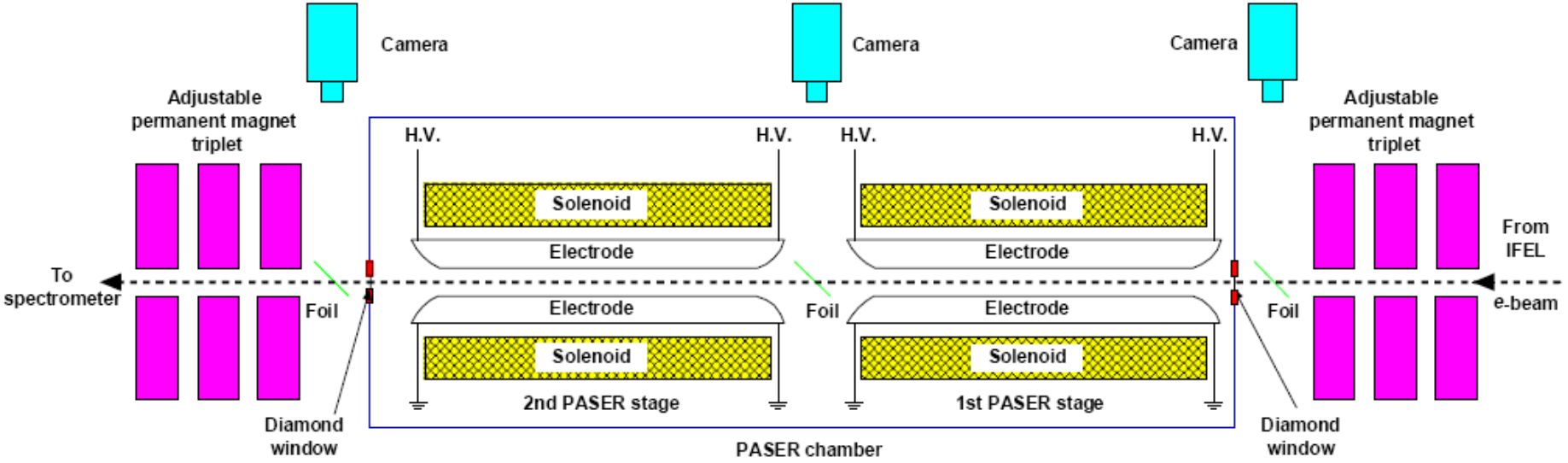
- Increasing the amount of charge
- Improve bunching efficiency (in wiggler)

Goal #2: Staging



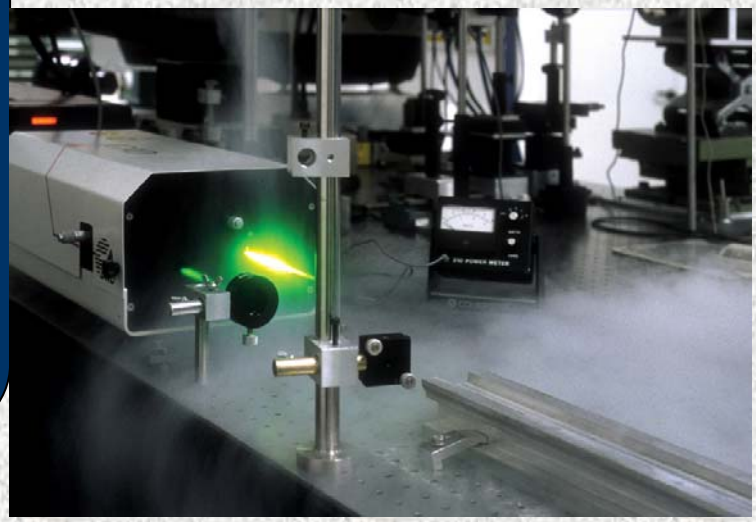
- Goal #1: High Gradient Operation @ IR
- Goal #2: Staging of PASER Cells
- Goal #3: Future Configurations

Goal #2: Staging



Goal #3: Future Configurations

- Argon$^+$ medium (476.5nm)
- Enhanced breakdown threshold
- 50 times more energetic photons than CO_2
- Potential high energy density stored
- Low operating pressure
  - Use gas-filled capillary discharge
  - Eliminate use of diamond windows
  - Reduce gas scattering effects



Goal #3: Future Configurations

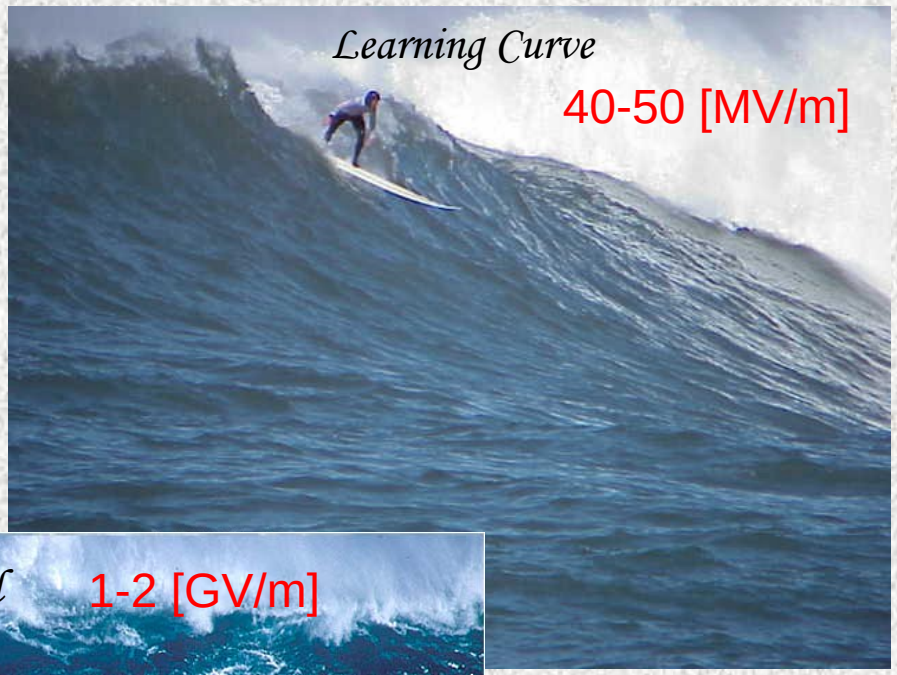
- Solid-state Nd:YAG (1.06 μm)
- 10 times more energetic photons
- Higher density of population inversion
- Electrons traveling through vacuum tunnel
  - Eliminate gas and windows scattering (emittance)
- Challenges:
  - Micro-bunches at the 1 micron wavelength
  - Efficient interaction requires GeV electrons

Summary of Proposed Program

- Goal #1: High Gradient Operation @ IR
  - enhance the energy density stored
  - improve bunch density
- Goal #2: Staging of PASER Cells
  - no need for external phase control
- Goal #3: Future Configurations
  - Ar^+ - breakdown threshold
  - Nd:YAG - high energy density

Road Map


Proof of Principle
0.5 [MV/m]


Learning Curve
40-50 [MV/m]


Ultimate Goal
1-2 [GV/m]

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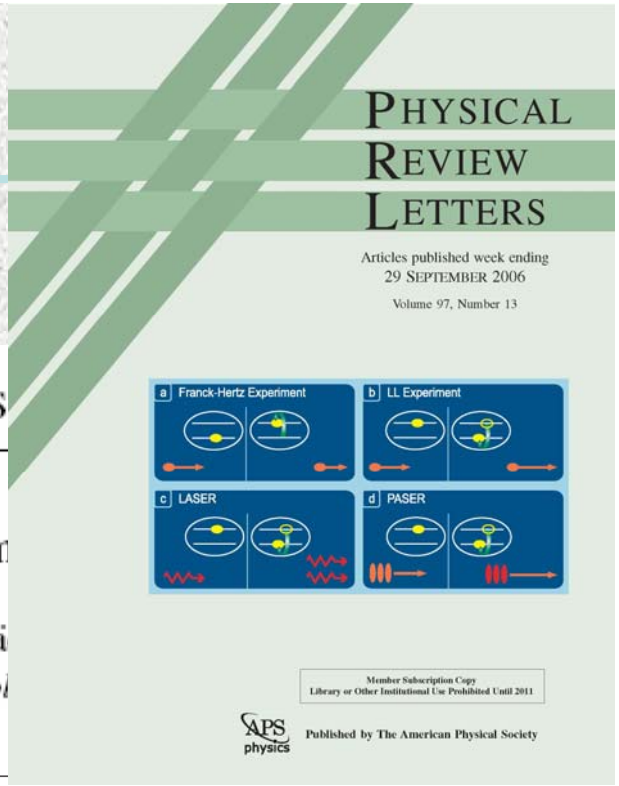
Concluding Remark



PRL 97, 134801 (2006) PHYSICAL REVIEW LETTERS

Experimental Observation of Direct Particle Acceleration by Stim

Samer Banna,* Valery Berezovsky, and Levi Schä
Department of Electrical Engineering, Technion-Israel Institute of Techno

APS NEWS

Physics News in 2006

A Supplement to *APS News* Edited by Phil Schewe, Ben Stein and Ernie Tretkoff

Particle Acceleration by Stimulated Emission of Radiation–PASER for Short

Particle Acceleration by Stimulated Emission of Radiation (PASER for short), a sort of particle analog of the laser process, has been demonstrated, for the first time, by a team of physicists from the Technion-Israel Institute of Technology using the accelerator facilities at the Brookhaven National Lab.